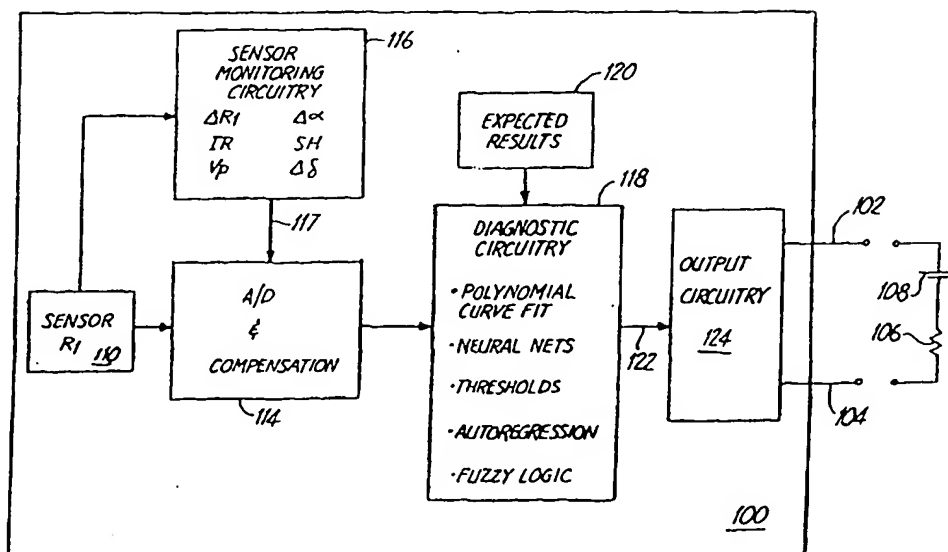




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(71) Applicant: ROSEMOUNT INC. [US/US]; 12001 Technology Drive, Eden Prairie, MN 55344 (US).			
(72) Inventors: ERYUREK, Evren; 4952 York Avenue South, Minneapolis, MN 55410 (US). LENZ, Gary; 6536 Mistral Lane, Eden Prairie, MN 55344 (US).			
(74) Agents: CHAMPLIN, Judson, K. et al.; Westman, Champlin & Kelly, P.A., International Centre, Suite 1600, 900 Second Avenue South, Minneapolis, MN 55402-3319 (US).			

(54) Title: DIAGNOSTICS FOR RESISTANCE BASED TRANSMITTER



(57) Abstract

A transmitter (100) in a process control system includes a resistance sensor (110) sensing a process variable and providing a sensor output. Sensor monitoring circuitry (116) coupled to the sensor (110) provides a secondary signal related to the sensor (110). Analog-to-digital conversion circuitry (114) coupled to the sensor output and the sensor monitoring circuitry (116) provides a digitized sensor output and a digitized secondary signal. Output circuitry (124) coupled to a process control loop (102, 104) transmits a residual life estimate related to residual life of the sensor. A memory stores a set of expected results (120) related to the secondary signal and to the sensor (110). Diagnostic circuitry (118) provides the residual life estimate as a function of the expected results (120) stored in the memory, the digitized sensor output and the digitized secondary signal.

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DIAGNOSTICS FOR RESISTANCE BASED TRANSMITTER

BACKGROUND OF THE INVENTION

The present invention relates to transmitters
5 of the type used in the process control industry. More specifically, the invention relates to diagnostics for process control transmitters.

Process control transmitters are used to monitor process variables in industrial processes. For
10 example, a transmitter might monitor pressure, temperature or flow and transmit such information back to a control room. Furthermore, some transmitters are capable of performing the control function directly. In order to monitor a process variable, the transmitter
15 must include some type of a sensor. For example, transmitters include sensors with resistances or capacitances which vary in response to broad temperature, deformations or strain which allow the transmitter to measure, for example, temperature,
20 pressure, flow, level, pH or turbidity.

As sensors age or are subjected to harsh environmental conditions, the accuracy of the sensor tends to degrade. It is possible to compensate for this degradation by periodically recalibrating the
25 transmitter. Typically, this requires an operator to enter the field and perform a calibration process on the transmitter. This is both inconvenient and time consuming for the operator. Further, it is difficult to determine the condition of a sensor, prior to its
30 ultimate failure.

It is also necessary for the sensors to be periodically replaced as they age. However, it is difficult to determine precisely when a replacement is

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necessary. Therefore, sensors are typically replaced well before their failure or they fail unexpectedly.

SUMMARY OF THE INVENTION

A transmitter in a process control system includes a resistance-based sensor sensing a process variable and providing a sensor output. Sensor monitoring circuitry coupled to the sensor provides a secondary signal related to the sensor. Analog-to-digital conversion circuitry coupled to the sensor output and the sensor monitoring circuitry provides a digitized sensor output and at least one digitized secondary signal. The six secondary signals include change in sensor resistance (ΔR_1), sheath to lead voltage (V_p), insulation resistance (R_{IR}), change in α ($\Delta\alpha$), change in δ ($\Delta\delta$) and self heating (SH). A memory stores a set of expected results related to the secondary signal and to the sensor. Diagnostic circuitry provides the residual life estimate as a function of the expected results stored in the memory, the digitized sensor output and the digitized secondary signal. Output circuitry coupled to a process control loop transmits a residual life estimate related to residual life of the sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a process control system including a transmitter in accordance with the present invention.

Figure 2 is a block diagram of a transmitter of the present invention.

Figure 3 is a simplified block diagram of a transmitter in accordance with one embodiment of the invention.

Figure 4 is a diagram showing a simplified neural network.

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Figure 5A is a diagram showing a neural network with a plurality of secondary input signals used to provide a residual lifetime estimate output from the transmitter.

5 Figure 5B is a graph of temperature sensor residual life versus time.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 is a diagram of process control system 2 including field mounted transmitter 40 coupled to control room 4 over a two wire process control loop 6. Transmitter 40 monitors the temperature of process fluid in process piping 18, but the present invention applies to any resistance based process variable measurement such as a resistance based pressure measurement. Transmitter 40 transmits temperature information to control room 4 over loop 6 by controlling the current flowing through loop 6. For example, the current flowing through loop 6 may be controlled between 4 and 20 mA and properly calibrated to indicate temperature. Additionally or in the alternative, transmitter 40 may transmit digital information related to temperature over loop 6 to control room 4 such as in a HART® or Fieldbus protocol. Transmitter 40 includes circuitry described herein in more detail which provides advanced diagnostics related to temperature sensor operation.

A block diagram of the present invention in a process control transmitter is shown in Figure 2. Transmitter 100 typically is configured as a two-wire transmitter, having two terminals 102, 104 which are electrically coupled to a controller which provides power for and communicates with transmitter 100. The controller is electrically modeled in Figure 2 as resistor 106 in series with voltage supply 108.

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Transmitter 100 may also practice the invention as a three or four wire transmitter.

The present invention can also be practiced in software which is resident in any of a number of places in a process system control system. In particular, the present invention as realized in software, can reside in a control system or even a final control element such as a valve, motor or switch. Furthermore, modern digital protocols such as Fieldbus, Profibus and others allow for the software which practices the present invention to be communicated between elements in a process control system, and also provide for process variables to be sensed in one transmitter and then sent to the software.

A resistance based sensor R_1 , labelled at 110, senses a process variable in a process. The process variable may be representative of pressure, temperature or other process variables which affect the resistance of sensor R_1 . Sensor 110 may be a piezoresistance based sensor, as is commonly used for sensing pressures, or a platinum resistance thermometer (PRT), which is commonly used for sensing temperature in a process control application. Output from sensor 110, which is an analog signal, is signal conditioned and digitized appropriately in A/D and compensation circuit 114. Output from sensor 110 also is electrically connected to sensor monitoring circuitry 116, which outputs onto bus 118 secondary signals representative of the change in resistance of sensor 110 (ΔR_1), insulation resistance (R_{IR}), case or sheath to lead voltage (V_p), change in alpha ($\Delta\alpha$), change in delta ($\Delta\delta$) and self heating (SH). Specifics of the circuits necessary for measuring each of the secondary signals are discussed below. A/D and compensation circuit 114 also compensates the primary variable, R_1 , for known repeatable errors via a look-up

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table or other method, such as a polynomial curvefit equation. Circuit 114 is preferably realized in a low power microprocessor, so as to conserve power. Conservation of power is important in the transmitter of the present invention because transmitter 100 is wholly
5 powered over a two wire loop formed by transmitter 100, supply 108 and resistor 106.

The digitized primary process variable sensed by sensor 110 in transmitter 100 and the digitized
10 secondary signals are coupled to diagnostic circuitry 118. Again with the intent of minimizing power consumption of transmitter 100, diagnostic circuitry 118 is preferably implemented in a low power microprocessor such as the Motorola 6805HC11.

15 A memory containing expected results (sometimes expressed as nominal values) for each of the secondary signals is labeled 120. The output of memory 120 is used as needed by the diagnostic circuitry 118 to provide an output 122 indicating the residual life of
20 sensor 110 (a "residual life estimate"). For secondary signal ΔR_1 , for instance, memory 120 stores a value representative of the expected change, or drift in the resistance of sensor 110 over a specific time period. The amount of expected change is dependent on the type
25 of sensor used, how it is manufactured, and the accuracy, in terms of drift, of the specific application for transmitter 100. The stored ΔR_1 is typically determined empirically by testing a number of production samples of sensor 110 and calculating an appropriate ΔR_1
30 number to store. Similarly, a value for R_{IR} is stored in memory 120. The value of stored R_{IR} is also empirically determined based on a number of production samples of sensor 110, and is representative of the impedance between a sheath of sensor 110 and sensor 110.

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Rosemount, the assignee of the present application, manufactures a number of types of PRTs, which may be used as sensor 110, and each type has a specified sheath to sensor impedance IR . A value for V_p is also stored in memory 120. The value of V_p is representative of the voltage between sensor 110 and the sheath, and should ideally be substantially zero. However, if moisture enters the sensor, the different metals in the sensor can generate a voltage through galvanic coupling. Empirical values of approximately zero are stored in memory 120 for this secondary signal after review of V_p for a number of production samples. A value for $\Delta\alpha$ and $\Delta\delta$ are also stored in memory 120, and are related to the temperature versus resistance characteristic for a PRT sensor 110. Manufacturing processes and specified accuracies set the expected values for $\Delta\alpha$ and $\Delta\delta$, based on empirical testing of a number of production samples of sensor 110. A value for SH is also stored in memory 120. The value of SH is representative of the expected time constant for cooling, or heating a PRT sensor 110 after a small deviation in the current is pulsed through the sensor.

Diagnostic circuitry 118 receives the contents of memory 120 and calculates a residual lifetime estimate 122. Diagnostic circuitry calculates a residual lifetime estimate of sensor 110 as a function of the expected results, the digitized output from sensor 110 and a digitized secondary signal. A preferred embodiment for the calculation method used in circuitry 118 is a set of polynomials. However, circuitry 118 can also be realized in a number of other ways, including neural nets, threshold circuits, autoregression models and fuzzy logic.

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Output circuitry 124 receives the residual life estimate from circuitry 118, as well as the conditioned output from sensor 110, and outputs it to the two wire loop, as appropriate.

5 Figure 3 is a block diagram of a temperature transmitter 40 connected to RTD temperature sensor 10 in accordance with the present invention. Transmitter 40 includes terminal block 44, current source 45, multiplexer 46, differential amplifier 48, high accuracy
10 A/D converter 50, microprocessor 52, clock circuit 54, memory 56 and input-output circuit 58.

 Terminal block 44 includes terminals 1 through 5 for coupling to, for example, RTD temperature sensor 10 or a thermo-couple temperature sensor 60 (shown in
15 Figure 5). Sensor 10 (and sensor 60) can be either internal or external to transmitter 40. Sensor 10 includes RTD sensor element 61 having a resistance R_1 which varies with changes in the ambient temperature immediately surrounding sheath 12. Leads 16 include
20 four element leads 62, 64, 66 and 68, and a sheath lead 70. Lead 62 is connected between sensor element 61 and terminal 4, lead 64 is connected between sensor element 61 and terminal 3, lead 66 is connected between sensor element 61 and terminal 2, and lead 68 is connected
25 between sensor element 61 and terminal 1. Sheath lead 70 is connected between sensor sheath 12 and terminal 5.

 Current source 45 is connected to terminal block 44 and supplies a measurement current I_s through terminal 4, sensor element 61, terminal 1, reference
30 resistance R_{REF} , pull-down resistance R_2 and ground terminal 72. Sensor element 61 develops a voltage drop across terminals 2 and 3 which is a function of the resistance R_1 and thus the temperature of sensor element

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61. Reference resistor R_{REF} is connected between terminal 1 and pull-down resistor R_2 .

Multiplexer 46 is divided into two sections, an active multiplexer having an output connected to the non-inverting input of differential amplifier 48 and a reference multiplexer having an output connected to the inverting input of differential amplifier 48. Microprocessor 52 controls multiplexer 46 to multiplex appropriate sets of analog signals, including signals from terminals 1 through 3, to the non-inverting and inverting inputs of differential amplifier 48. Differential amplifier 48 has an output connected to A/D converter 50. In one embodiment, A/D converter 50 has an accuracy of 17 bits and a conversion rate of 14 samples/second. A/D converter 50 converts the voltage at the output of differential amplifier 48 into a digital value and provides that value to microprocessor 52 for analysis or for communication over process control loop 42 through input-output circuit 58.

Input-output circuit 58, in a preferred embodiment, includes a HART® communication section, a FIELDBUS communication section and a 4-20 mA analog loop section for analog or bi-directional digital communicating over loop 42 according to a selected protocol in a known manner. Other protocols can also be used, for example, a four-wire configuration may be employed in which power is received from a separate source. Loop 42 also provides power to the various components of transmitter 40 through input-output circuit 58. Transmitter 40 is wholly (completely) powered by the two-wire loop 42.

Memory 56 stores instructions and information for microprocessor 52, which operates at a speed determined by clock circuit 60. Clock circuit 60

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includes a real time clock and a precision high speed clock, which are also used to sequence the operation of A/D converter 50. Microprocessor 52 performs several functions, including control of multiplexer 46 and A/D converter 50, control of communication over loop 42, temperature calculations, drift correction, circuitry diagnostics, storage of transmitter configuration parameters and performing sensor diagnostics.

Microprocessor 52 employs the following equation to compute the major value of the temperature of RTD sensor element 61:

$$R_1 = \frac{V_{R1}}{V_{RREF}} (R_{REFNOM}) \quad \text{Equation 1}$$

where:

R_1 = resistance of RTD sensor element 61;
 V_{R1} = voltage drop across the RTD sensor element 61;
 V_{RREF} = voltage drop across resistance R_{REF} ; and
 R_{REFNOM} = nominal resistance of the reference resistance R_{REF} in Ohms, and/or stored in memory 56.

Microprocessor 52 measures the voltage drop V_{R1} across RTD sensor element 61 between terminals 2 and 3, and the voltage drop (V_{RREF}) across reference resistance R_{REF} with multiplexer 46. In a four-wire resistance measurement such as the one shown in Figure 2, the voltage drop across the connections to terminals 2 and 3 is largely eliminated, since substantially all of the current I_s flows between terminals 1 and 4, and has little impact on the accuracy of the measurement. Microprocessor 52 converts the measured resistance R_1 into temperature units with a look-up table or suitable equations stored in memory 30.

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Johnson noise can also be used to measure resistance for use in measuring resistance of PRT sensor 61 or for uses, as appropriate, in the measurement of six secondary signals below.

5 **II. MEASUREMENT OF SECONDARY SIGNALS**

The present invention measures, or determines, secondary signals/inputs which are used in performing advanced diagnostics on the transmitter. The secondary signals include: change in sensor resistance (ΔR_1),
10 sheath to lead voltage (V_p), insulation resistance (R_{IR}), change in α ($\Delta\alpha$), change in delta ($\Delta\delta$), and self heating (SH).

A. Change In Sensor Resistance

Change in sensor resistance (ΔR_1) of RTD
15 sensor element 61 is determined by monitoring R_1 as described above. Microprocessor monitors R_1 and time information using clock 54. Values of R_1 and the time at which they occurred is stored in memory 56. In one embodiment, only changes in R_1 and the time period over
20 which the change occurred are stored.

B. Sheath To Lead Voltage And Insulation Resistance

Transmitter 40 may also determine sheath to lead voltage (V_p) and insulation resistance (R_{IR}) using a sheath-to-lead voltage measurement circuit 76 and an
25 insulation resistance measurement circuit 80. Within temperature sensor 10, a sheath-to-lead voltage is sometimes generated between sensor sheath 12 and sensor element 61 because of dissimilar metals in the sensor being separated by an electrolyte made up of ceramic
30 impurities (ionics) in the sensor and water entering into the system. The sheath-to-lead voltage is shown in phantom in Figure 3 as a voltage source V_p . Transmitter 40 measures voltage V_p through sheath-to-lead voltage measurement circuit 76. When measuring the sheath-to-

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lead voltage, microprocessor 52 turns off external voltage or current sources, such as current source 45, that are connected to temperature sensor 10 such that amplifier 78 measures only the voltage generated by electrolytic action in sensor 10.

Circuit 76 includes an amplifier 78 with an inverting input coupled to terminal 1, a non-inverting input coupled to terminal 5 and an output coupled to A/D converter 50. Amplifier 78 is therefore electrically placed across the insulation resistance barrier in sensor 10 (i.e. across sheath 12 and one of the element leads 62, 64, 66 and 68), so as to measure the voltage difference V_p across this barrier. A/D converter 50 samples the sheath-to-lead voltage provided by amplifier 78 at a selected rate under the control of microprocessor 52. Microprocessor 52 stores the resulting voltage samples in memory 56, and determines a residual lifetime estimate as a function of the stored expected value of V_p and the newly stored V_p value, according to a polynomial equation.

Insulation resistance measurement circuit 80 measures the insulation barrier within sensor 10 between sensor sheath 12 and sensor element 61, which is represented in Figure 3 by insulation resistance R_{IR} (shown in phantom). Sensor sheath 12 should be electrically isolated from sensor element 61 and element leads 62, 64, 66 and 68. Insulation resistance R_{IR} is the resistance between sensor sheath 12 and any one of the element leads 62, 64, 66 and 68. The insulation resistance R_{IR} should be very high in a good sensor, on the order of 100-500 megohms. An insulation resistance below 1 megohm might be considered a failed sensor.

Measurement circuit 80 includes voltage source 82, measurement resistance R_j , amplifier 84 and switch

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86. Voltage source 82 is connected between measurement resistance R_3 and ground terminal 72. Measurement resistance R_3 is connected in series with voltage source 82, switch 86 and insulation resistance R_{IR} , which is in series with reference resistance R_{REF} and pull-down resistance R_2 . Measurement resistance R_3 , insulation resistance R_{IR} , reference resistance R_{REF} and pull-down resistance R_2 form a current path from voltage source 82 to ground terminal 72. Current flowing through the current path is the leakage current from sensor sheath 12 to RTD sensor element R_1 , which is a function of the insulation resistance R_{IR} . The voltage drop across measurement resistance R_3 is a function of the leakage current I_L and thus the insulation resistance R_{IR} . The non-inverting and inverting inputs of amplifier 84 are connected across measurement resistance R_3 to measure the voltage drop across measurement resistance R_3 . Amplifier 84 has a very low input bias current. The output of amplifier 84 is connected to A/D converter 50 which converts the voltage measurement to a digital value at a selected rate under the control of microprocessor 52. Microprocessor 52 stores the resulting digital values of R_{IR} in memory 56. When microprocessor 52 makes an insulation resistance measurement, microprocessor 52 turns off current source 45 and closes switch 86 to connect measurement circuit 80 to terminal 5 to drive leakage current I_L through insulation resistance R_{IR} . Once the measurement has been completed, microprocessor 52 opens switch 86, thereby disconnecting voltage source 82 from sensor sheath 12. The diagnostic circuitry within microprocessor 52 calculates a residual lifetime output based on the expected value of R_{IR} stored in memory 56

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and the newly measured value R_{JR} , according to a polynomial equation.

C. Measurement of Sensor Alpha (α), and Delta (δ):

Alpha (α) and delta (δ) are constants related
5 to the slope of resistance versus temperature plot for
a specific resistance based sensor. Their calculation
is discussed in PRT Handbook Bulletin 1042, dated
February 1985, published by Rosemount and incorporated
by reference. Three different values of R_1 are stored
10 in memory 56 sometimes taken over a start-up period for
the process, sometimes taken over a period of days in
order to get a sufficiently large difference between the
 R_1 values, before constants α and δ are calculated in
microprocessor 52. Once calculated, the newly computed
15 values of α and δ are compared to the expected values of
 α and δ stored in memory 56, to compute $\Delta\alpha$ and $\Delta\delta$.

A residual life estimate is computed from $\Delta\alpha$
and $\Delta\delta$ based on the magnitude of $\Delta\alpha$ and $\Delta\delta$, output to
I/O circuitry 58 and sent over loop 42.

20 D. Self Heating

The self heating measurement is performed by
injecting a known current I_{SH} into RTD 61 using current
source 140. Typically, other current paths are
disconnected from RTD 61 so that the entire current I_{SH}
25 flows through RTD 61. Current I_{SH} causes thermal
heating of RTD 61 which results in a change of
resistance R_1 , measured as described above. The change
in resistance R_1 due to current I_{SH} is monitored by
microprocessor 52 for use as described below.

30 Additionally, the technique can be used to
determine the temperature time constant of the sensor.
Immediately after the sensor current is returned to a
normal level, a series of direct DC readings are taken
to measure the time for the sensor temperature to return

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to a constant value again. The time constant is determined from this time period and provided as a secondary signal. If the process temperature is moving, this technique, taken many times over a period of time, is averaged out to get a final value. The value of the time constant changing over a long period of time indicates that the thermal connection between the sensor and t-well degrading or the insulation between the sensor element and sheath wearing or degrading.

III. DIAGNOSTIC CIRCUITRY

Microprocessor 52 performs diagnostics related to operation of transmitter 40 using at least one of the six secondary signals discussed above. The following describes a number of embodiments for realizing the diagnostic circuitry in transmitter 40. The residual lifetime estimate may be representative of an impending sensor failure. In one embodiment, the state of health output is indicative of the remaining life of the sensor such that sensor replacement may be timed appropriately. An alarm signal may also be sent to control room 4 prior to sensor failure.

A. Polynomial Curvefit

A preferred embodiment of diagnostic circuitry 52 in the present invention uses empirical models or polynomial curve-fitting.

A polynomial-like equation which has a combination of the six secondary signals as the variable terms in the polynomial, together with constants stored in memory 56 is used for computing the residual lifetime estimate. If transmitter memory is limited, the constants and/or the equation may be sent over the two wire loop to transmitter 40.

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B. Neural Networks

One diagnostic circuit is implemented with a multi-layer neural network. Although a number of training algorithms can be used to develop a neural network model for different goals, one embodiment includes the known Backpropagation Network (BPN) to develop neural network modules which will capture the nonlinear relationship among a set of input and outputs(s). Figure 4 shows a typical topology of a three-layer neural network architecture implemented in microprocessor 52 and memory 56. The first layer, usually referred to as the input buffer, receives the information, and feeds them into the inner layers. The second layer, in a three-layer network, commonly known as a hidden layer, receives the information from the input layer, modified by the weights on the connections and propagates this information forward. This is illustrated in the hidden layer which is used to characterize the nonlinear properties of the system analyzed. The last layer is the output layer where the calculated outputs (estimations) are presented to the environment.

Figure 5A shows a schematic for residual life estimation of temperature sensors using a neural network model, the six secondary signals include changes in sensor resistance (ΔR_1), insulation resistance (IR), case to lead voltage (V_p), change in α ($\Delta\alpha$), self heating (SH) and change in δ ($\Delta\delta$). Figure 5B is a graph of residual life versus time and shows sample outputs generated by the network of Figure 5A.

The secondary signals may be used in various embodiments either alone, or in any of their combinations. The number of inputs may differ and

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depending on the type of the resistance based sensor, one or more of those parameters may not be included.

The secondary signals essentially represent the state of the RTD sensor 61 or of a thermo-couple, as appropriate, and follow related patterns which allow microprocessor 52 to perform pattern recognition to identify failures and/or developing problems.

C. Threshold Circuitry

This embodiment of the diagnostic circuitry 52 uses a set of if - then rules to reach a conclusion on the status of the temperature sensor RTD 61 and may easily be implemented in analog circuitry. The previously mentioned input parameters (either all, or a subset) are monitored and their present values are compared to upper and lower boundaries. The upper and lower boundaries are empirically set by extensive testing of many of sensor 61. A decision is made based upon the comparison.

In a digital embodiment of this type of diagnostic circuitry, the values of the secondary signals are monitored and compared with their acceptable ranges by microprocessor 52.

The following is a sample if-then rule for sensor change in resistance (ΔR_1):

If ΔR_1 is multiplied by the percentage greater than RH, then residual life estimate of sensor 61 is n days.

where: X = percentage boundary

ΔR_1 is the change in the resistance value of the sensor over a known time period,
RH is the upper boundary of the acceptable range.

Similarly, IR, V_p , SH, change in α ($\Delta\alpha$), and change in δ ($\Delta\delta$) will have corresponding upper and lower

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limits are used toward assigning the resultant values to be utilized in a decision making rules set.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention. In particular, the present invention may be used for voltage based sensors, such as a thermo-couple or a voltage-based sensor.

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WHAT IS CLAIMED IS:

1. A transmitter in a process control system, comprising:
 - a resistance sensor sensing a process variable and providing a sensor output;
 - sensor monitoring circuitry coupled to the sensor providing a secondary signal related to sensor;
 - analog to digital conversion circuitry coupled to the sensor output and the sensor monitoring circuitry and providing a digitized sensor output and a digitized secondary signal;
 - output circuitry coupled to a process control loop for transmitting a residual life estimate;
 - a memory storing set of expected results related to the secondary signal and to the sensor; and
 - diagnostic circuitry coupled to the digitized secondary signal and to the memory, for providing the residual life estimate as a function of the expected results in the memory and the digitized secondary signal.
2. The transmitter of claim 1 wherein the diagnostic circuitry comprises a neural network.
3. The transmitter of claim 1 wherein the diagnostic circuitry comprises fuzzy logic.
4. The transmitter of claim 1 wherein the diagnostic circuitry includes an empirical model to determine the residual lifetime estimate output.
5. The transmitter of claim 1 wherein the diagnostic circuitry compares the secondary signal with

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a threshold to determine the residual lifetime estimate output.

6. The transmitter of claim 1 wherein the diagnostic circuitry includes an auto regression model which determines the residual lifetime of the sensor.

7. The transmitter of claim 1 wherein the secondary signal comprises change in sensor resistance.

8. The transmitter of claim 1 wherein the secondary signal comprises a voltage between a sheath and a lead of the resistance sensor.

9. The transmitter of claim 1 wherein the secondary signal comprises a resistance of insulation of the sensor.

10. The transmitter of claim 1 wherein the secondary signal comprises alpha (α) of the resistance sensor.

11. The transmitter of claim 1 wherein the secondary signal comprises delta (δ) of the resistance sensor.

12. The transmitter of claim 1 wherein the secondary signal comprises a self heating signal of the resistance sensor generated in response to signal applied to the resistance sensor.

13. A method for providing a residual life estimate of sensor, comprising:

sensing and digitizing an output of the sensor to provide a digitized sensor output;

sensing and digitizing a property related to the lifetime of the sensor to provide a digitized secondary output;

storing an expected output related to the life of the sensor and the secondary output; and

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calculating a residual lifetime estimate as a function of the expected output, the digitized secondary output and the digitized sensor output.

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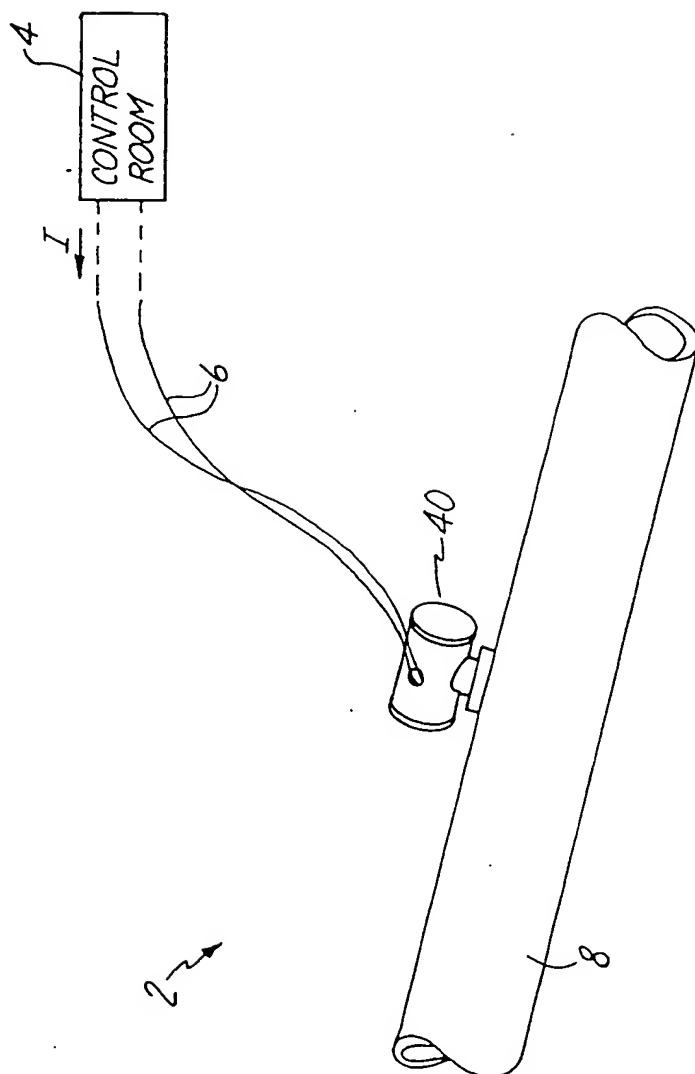


Fig. 1

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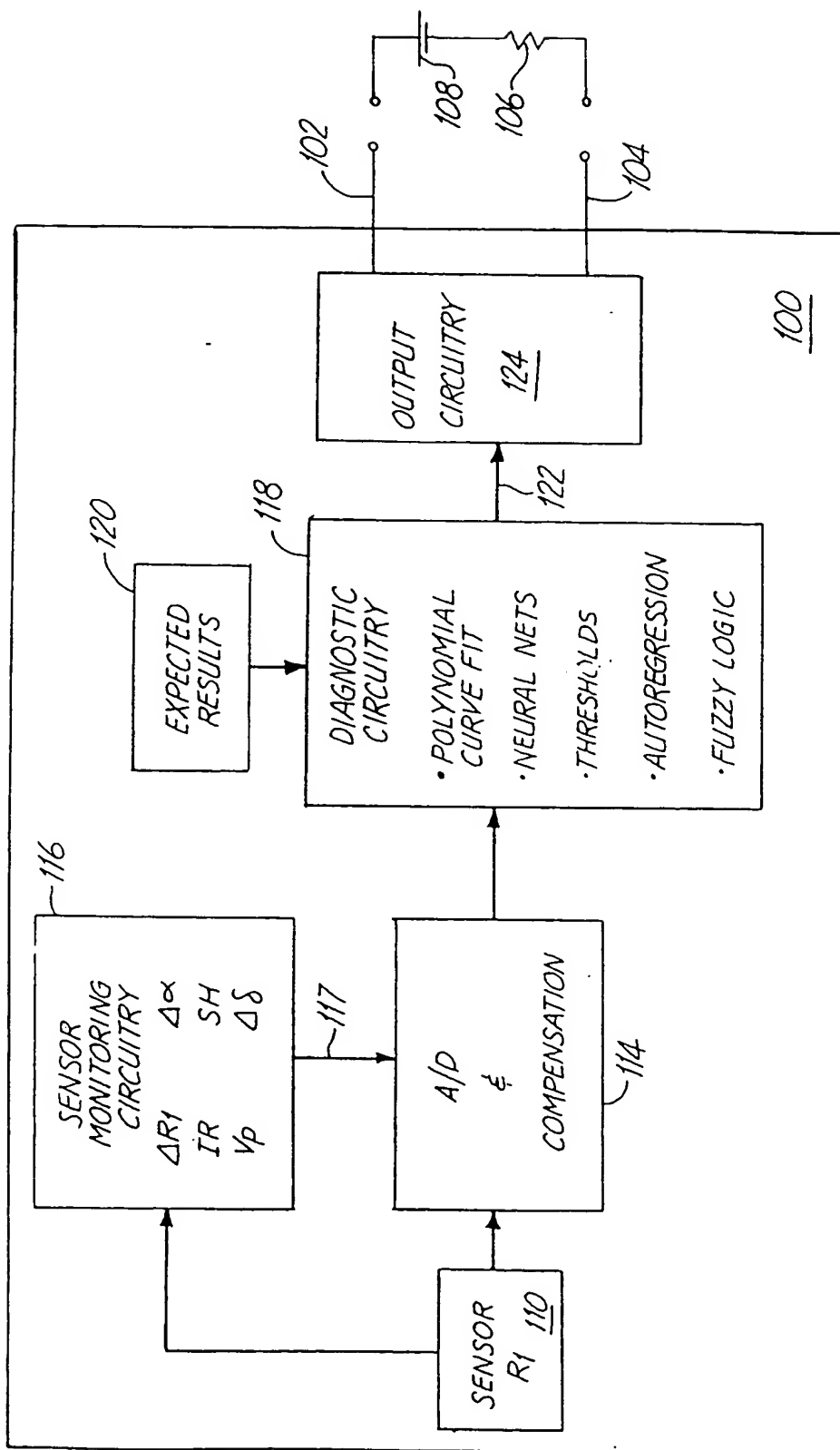
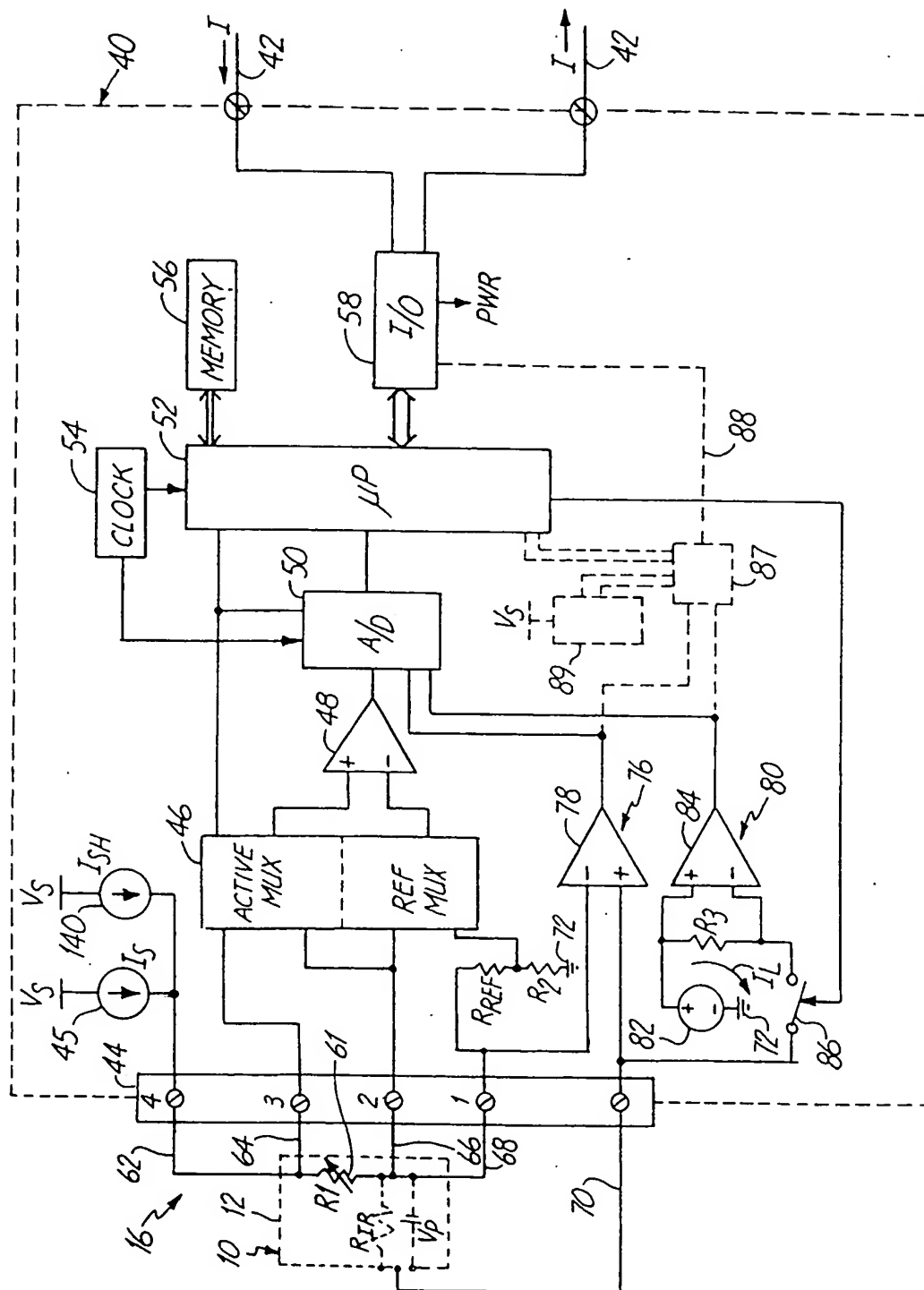


Fig. 2

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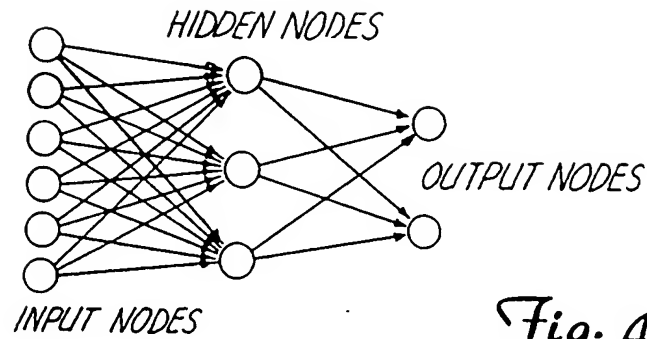


Fig. 4

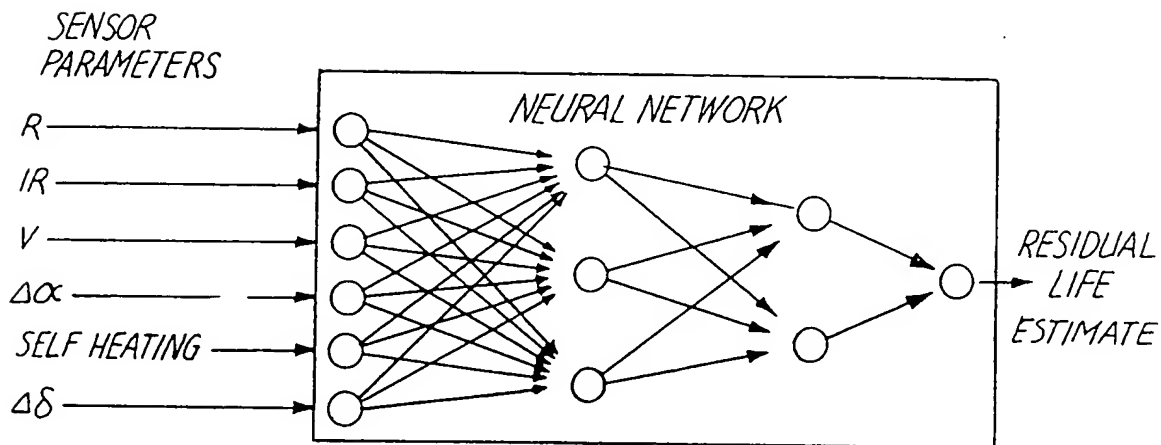


Fig. 5A

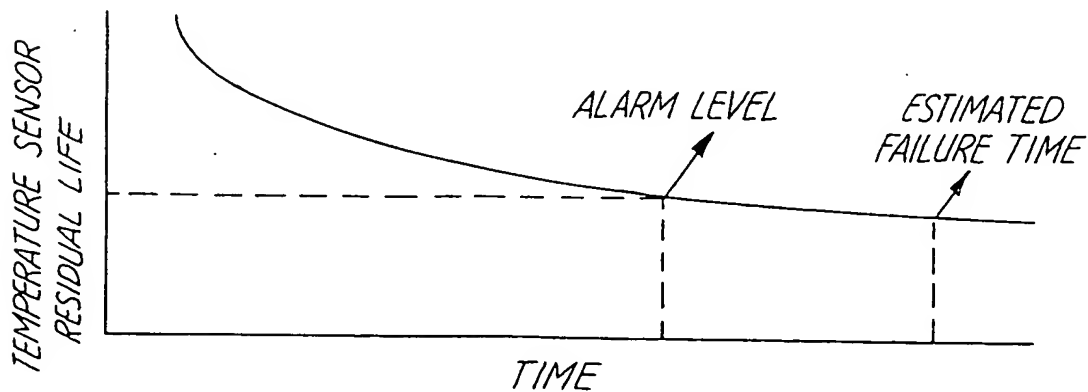


Fig. 5B

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 97/19045

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G08C19/02 G07C3/00

According to International Patent Classification(IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G08C G07C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 528 940 A (YAMAMOTO YOSHIMI ET AL) 25 June 1996 see column 1, line 7 - column 2, line 34 see column 3, line 13 - column 4, line 5 see column 6, line 55 - column 7, line 62 see column 10, line 62 - column 11, line 6 see figures 1,7,11,15 ---	1,13
A	ORRISON IV G A: "TAKING FULL ADVANTAGE OF SMART TRANSMITTER TECHNOLOGY NOW" CONTROL ENGINEERING INTERNATIONAL, vol. 42, no. 1, 1 January 1995, NEWTON,US, pages 59-61, XP000500027 see page 59, right-hand column, line 31 - page 60, middle column, line 3 --- -/--	1

☒ Further documents are listed in the continuation of box C.☒ Patent family members are listed in annex.

* Special categories of cited documents :

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Date of the actual completion of the international search

18 December 1997

Date of mailing of the international search report

02/01/1998

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2250 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Wanzeele, R

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 97/19045

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 018, no. 627 (P-1834), 29 November 1994 & JP 06 242192 A (OMRON CORP;OTHERS: 01), 2 September 1994, see abstract ---	1,3,6,13
A	PATENT ABSTRACTS OF JAPAN vol. 013, no. 165 (P-860), 20 April 1989 & JP 64 001914 A (MITSUBISHI HEAVY IND LTD), 6 January 1989, see abstract ---	1,3
A	PATENT ABSTRACTS OF JAPAN vol. 096, no. 001, 31 January 1996 & JP 07 234988 A (MITSUBISHI HEAVY IND LTD), 5 September 1995, see abstract ---	1,2
A	DE 40 08 560 A (HITACHI LTD) 20 September 1990 see abstract -----	1,13

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 97/19045

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5528940 A	25-06-96	JP 6235672 A	23-08-94
DE 4008560 A	20-09-90	JP 2544498 B	16-10-96
		JP 3015768 A	24-01-91
		US 5608845 A	04-03-97